2Pb1-4

Measurement of acoustic characteristics of mouthpiece type ultrasonic transducer for oral treatment
口腔内治療応用に向けたマウスピース型超音波振動子の音響特性評価*

Shohei Fukuda[1†], Marie Tabaru[1], Kentaro Nakamura[1], Mutsuo Ishikawa[2], Kazuki Satomi[3], Kazuaki Nishimura[3] ([1]Tokyo Tech; [2]Toin Univ. of Yokohama; [3]Tohoku Univ.)

福田翔平 [1†]，田原麻梨江 [1]，中村健太郎 [1]，石河睦生 [2]，里見和紀 [3]，西村壽晃 [3]（[1]東工大　[2]桐蔭横浜大　[3]東北大）

1. Background

Low-power ultrasound has been known to promote the healing of osteonecrosis of the jaw (ONJ)[1]. However, there is no such an ultrasonic device for the oral cavity. We have developed a rod-shaped ultrasonic device working at 3 MHz with a tip of several millimeter and confirmed the effect of the healing[2]. The device is supposed to be held by hand. In this study, we proposed mouthpiece type ultrasonic transducer to fix the device in the oral cavity. We assume that piezoelectric material is put in the silicone impression material, which is used in dentistry. In this report, acoustic characteristics of the silicone impression material is investigated.

2. Measurement of the longitudinal velocity and the attenuation coefficient of impression materials

2.1 Methods

The longitudinal velocity and the attenuation coefficient of impression materials were estimated by the transmission method. A focused transducer (V320, Olympus) with diameter and focal length of 13 mm, and center frequency of 7.5 MHz was used as a transmitter. The focal width l is given by

$$l=2.44\times\frac{X}{D}\times\lambda, \quad (2.1)$$

where λ is the wavelength, X is the focal length, and D is the diameter of the probe. Calculated l (= 3.66 mm) was smaller than the sample diameter (= 29 mm). A planar transducer (V320, Panametrics) with diameter of 13 mm and center frequency of 7.5 MHz was used as a receiver. The water temperature was 22℃. The distances between the transmitter and sample was 13mm, and the transmitter and receiver was 26 mm, respectively. A burst wave (5 waves, 1 Vpp) with frequency of 1.0-4.0 MHz (0.25 MHz interval) was output from a function generator (AFG3251, Tektronix). The burst wave was amplified 10 times by a power amplifier (HSA4101, NF), and the focused transducer was drove with 10 Vpp. The received signal received by the planar transducer was attenuated by using a pulsar receiver (5052PR, Panametrics), and observed by an oscilloscope (DL9040L, Yokogawa, 1024 times average, time width 200 μs, sampling frequency 625 MHz). Fig. 1 shows the samples of impression materials. The densities of SHOFU (S1), GC (S2), 3M ESPE (S3) and TOKUYAMA DENTAL (S4) are 1429, 1535, 1483 and 1482 kg/m^3, respectively. Here, attenuation is given by

$$\text{L [dB/cm]}=\frac{10\log\left|\frac{A_1}{A_2}\right|^2-2\times10\log\frac{(Z_1+Z_2)^2}{4Z_1Z_2}}{d}, \quad (2.2)$$

where A_1 and A_2 are the amplitudes of incident and transmitted wave, Z_1 and Z_2 are acoustic impedances of water and the sample, and d is thickness of the sample.

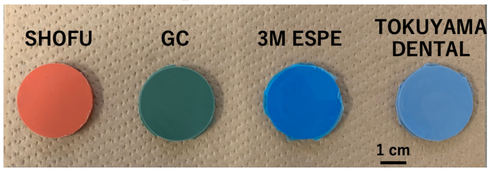

Fig. 1 Impression materials.

2.2 Result and discussion

Fig. 2 shows the received waveform with and without sample (S1) at 1 MHz. The difference between the incident time (t_0 = 10.4 μs) and the first reception time (without impression material) (t_1 = 28.5 μs) was 18.1 μs. Theoretical value of arrival time was calculated to be 17.5 μs, which was close to the experimental result. The signals appear every 36 μs due to the multiple reflection between the transmitter and the receiver. Table 1 shows summary of the longitudinal wave velocity and the acoustic impedance of water and the samples where the density of water was 1000 kg/m^3. The reference values of velocity of silicone rubber is 1050 m/s[3] with the experimental error of 0.1-7.2%. The acoustic impedances of the samples were close to water. Fig. 3 shows the attenuation coefficient calculated with Eq. (2.2) and power approximation curves of the samples. S2 had the largest attenuation. This might be because S2 is harder than the others and has higher filler filling rate[4]. Generally, the radiated sound pressure increases with the smaller attenuation. The results show that S1 had the smallest attenuation.

Table 1 Summary of acoustic characteristics.

	Velocity [m/s]	Acoustic impedance $\times 10^6$ [kg/(m^2 • sec)]
Water	1458 ± 9.1	1.46 ± 0.0091
S1	974 ± 5.4	1.39 ± 0.0077
S2	1051 ± 7.0	1.61 ± 0.0108
S3	1019 ± 6.4	1.51 ± 0.0095
S4	988 ± 6.1	1.46 ± 0.0090

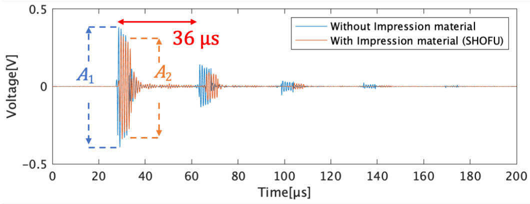

Fig. 2 Received waveform (@1 MHz).

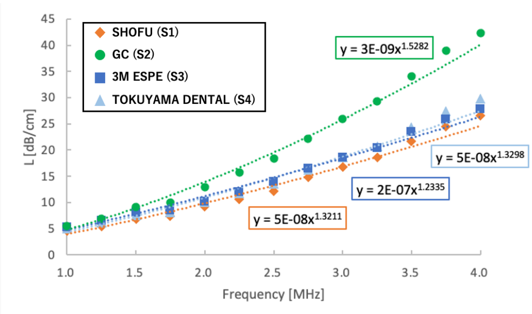

Fig. 3 Attenuation coefficients.

3. Measurement of the radiated sound pressure

3.1 Fabrication of mouthpiece type ultrasonic transducer

Fig. 4 shows an example of fabrication process. First, we made a plaster assuming ONJ (①). The red circle part has no teeth to secure a place to inject impression material. Then, a mouthpiece was fabricated, and impression material (S1) was injected from the cavity of the mouthpiece (②). PZT (lead zirconate titanate) (5×5 mm^2) was embedded in the impression material. Finally, the mouthpiece was removed from the plaster for the following measurement. The distance between the PZT and radiation surface of impression material was about 1 mm.

3.2 Estimation of sound intensity

The radiated sound pressure of the fabricated mouthpiece type ultrasonic transducer was measured with a hydrophone (TNU001A, Eastek). The sound intensity (spatial-peak, time-average) was calculated, where the duty cycle of 20% and vibration area of 23 mm^2 were used. Fig. 5 shows the calculated sound intensity vs. driving voltage. The required intensity of 30 mW/cm^2[1] for treatment was obtained with the voltage of 15 V0p.

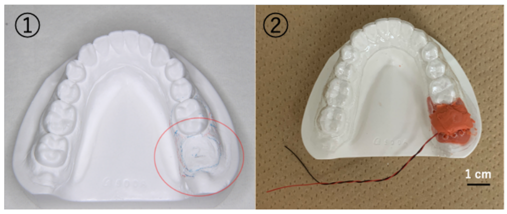

Fig. 4 Fabrication process: ① plaster assuming ONJ and ② mouthpiece with impression material.

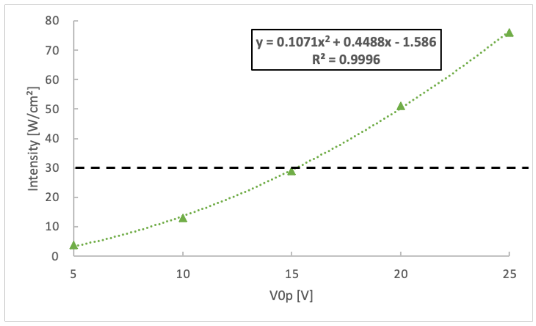

Fig. 5 Sound intensity (@1 MHz).

4. Conclusion

The acoustic characteristics of the impression materials were investigated. The temperature characteristics (37°C) will be studied.

Acknowledgment

This work was supported by Research Center for Biomedical Engineering.

References

[1] Wu et al., J. of Surgical Research 182 (1), 55 - 61, 2013.
[2] Nishimura et al., Annual Report on Research. Center for Biomedical Engineering, 106, 2019.
[3] Saitou et al., JSMER, 19, 11-17, 2006.
[4] Inoue et al., JSDMD, 2 (4), 408-413, 1983.